Prompt-neutron spectra from a general description of the fission process*

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Abstract

A new semi-empirical model of the fission process is described, which covers most of the properties of the fission fragments and the emitted neutrons and photons in a global and consistent way. The model is based on fragment shells that are deduced from measured fission-fragment mass distributions, assuming that the macroscopic contribution of the compound nucleus and the microscopic contributions of the nascent fragments in the potential-energy surface are separable. The distributions of the collective coordinates are attributed to the motion of the quantum oscillators in their respective potential pockets perpendicular to the fission path. Different contributions to the excitation energies of the final fragments and their division at scission are described with the help of statistical mechanics. Intrinsic excitation energies of the fragments at scission are consistently described together with the even-odd effect in fission-fragment Z distributions. Mass-dependent equilibrium deformations of the nascent fragments are adjusted to measured average prompt-neutron multiplicities. A unique set of parameters is found, which reproduces a large variety of measured data for all heavy fissioning systems with a good precision. In contrast to most available models, this approach is applicable to fissioning systems, for which no experimental data are available.

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1 Introduction

Global parametrisations and very elaborate models have been developed for calculating the energy spectra of prompt fission neutrons and their multiplicity distributions. Most of them are based on measured mass-TKE distributions of the fission fragments. With the help of the Q values for specific nuclear-charge and mass splits and by considering the initial excitation energy, the total excitation energy TXE of the fragments can directly be deduced. With an assumption on the division of the TXE between the fragments, which needs to be consistent with the observed mass-dependent neutron multiplicities, the initial conditions of both fragments for a statistical de- excitation code of the Weisskopf or Hauser-Feshbach type are determined. The task is appreciably more difficult when this experimental basis, the measured mass-TKE distribution, is not available. In this case, this information must be provided by a model calculation. The GEF code has been developed for this purpose. It is a semi-empirical model of the fission process, which covers most of the properties of the fission fragments and the emitted neutrons and photons in a global and consistent way. In addition to the mass-TKE distribution it also calculates the division of the TXE between the fragments and the angular momenta of the fragments. Moreover, the specific initial conditions of each individual fragment are given. This report gives an overview on the underlying physics ideas and the general technical features of the code and presents some results. More detailed information on the code can be found in the report JEF/DOC 1423 [1] and, if needed, in the source of the code [2]. The final aim of the present work is to provide predictions for the multiplicities and the energy spectra of the prompt fission neutrons.

2 Fission channels

2.1 Experimental systematics

Figure 1 gives an overview on the measured mass and nuclear-charge distributions of fission products from low-energy fission. Fission of target nuclei in the actinide region, mostly induced by neutrons, shows predominantly asymmetric mass splits. A transition to symmetric mass splits is seen around mass 258 in spontaneous fission of fusion residues. Electromagnetic-induced fission of relativistic secondary beams covers the transition from asymmetric to symmetric fission around mass 226 [3]. A pronounced fine structure close to symmetry appears in ^{201}Tl [4] and in ^{180}Hg [5]. It is difficult to

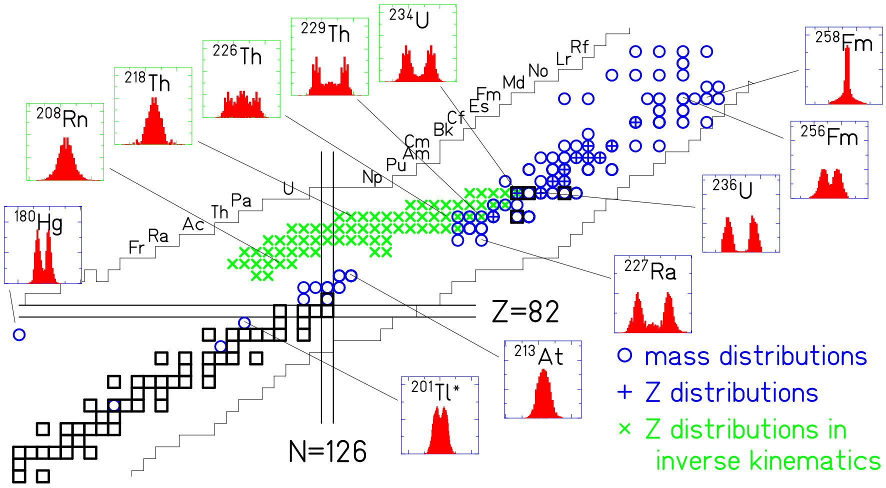

Figure 1: General view on the systems for which mass or nuclear-charge distributions have been measured. The distributions are shown for 12 selected systems. Blue circles (blue crosses): Mass (nuclear-charge) distributions, measured in conventional experiments [4, 5], and references given in [3]. Green crosses: Nuclear-charge distributions, measured in inverse kinematics [3].

observe low-energy fission in this mass range. Thus, ^{201}Tl could only be measured down to 7.3 MeV above the fission barrier due to its low fissility, which explains the filling of the minimum between the two peaks. Only ^{180}Hg was measured at energies close to the barrier after beta decay of ^{180}Tl. Considering the measured energy dependence of the structure for ^{201}Tl [4], the fission characteristics of these two nuclei are rather similar. Also other nuclei in this mass region show similar features, which have been attributed to the influence of fragment shells [6]. These shells are different from those governing the asymmetric fission of the actinides. They are not considered in the present model that concentrates on heavier nuclei with mass numbers $A > 200$, which are more important for technical applications.

2.2 Size of the heavy fragment in asymmetric fission

In the range where asymmetric fission prevails, e.g. from ^{227}Ra to ^{256}Fm, the light and the heavy fission-product components gradually approach each other, see figure 1. A quantitative analysis reveals that the mean mass of

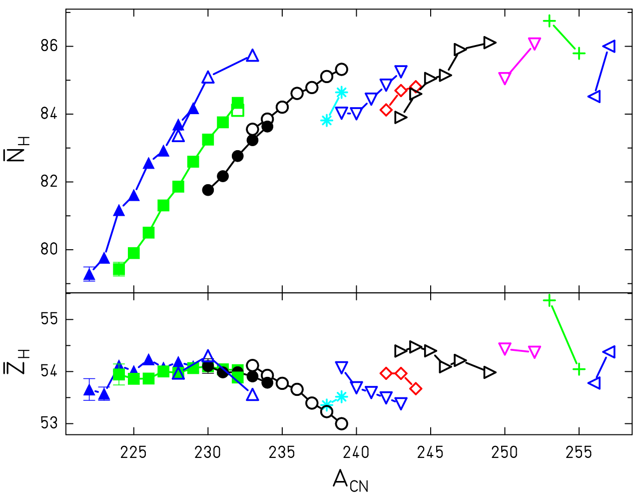

Figure 2: Mean neutron and proton number of the heavy component in asymmetric fission in the actinide region before the emission of prompt neutrons. The values were deduced from measured mass and nuclear-charge distributions using the semi-empirical GEF code [2] for the correction of charge polarization and prompt-neutron emission. Open symbols denote results from conventional experiments, full symbols refer to an experiment with relativistic projectile fragments of ^{238}U [3]. Data points for the same Z_{CN} are connected (See [2] for references of the underlying experimental data.)

the heavy component stays approximately constant [7] at about $A = 140$. This has been explained by the influence of a deformed ($\beta \approx 0.6$) fragment shell at $N = 88$ and the spherical shell at $N = 82$ [8], suggesting that the position of the heavy fragment is essentially constant in neutron number.

New data on Z distributions over long isotopic chains [3], however, reveal very clearly that the position in neutron number varies systematically over more than 7 units, while the position in proton number is approximately constant at $Z = 54$, see figure 2. The rather short isotopic sequences covered in former experiments did not show this feature clearly enough and gave the false impression of a constant position in mass. This finding represents a severe puzzle to theory, since shell-model calculations do not show any shell stabilization near $Z = 54$ at $\beta \approx 0.6$ [8, 9].

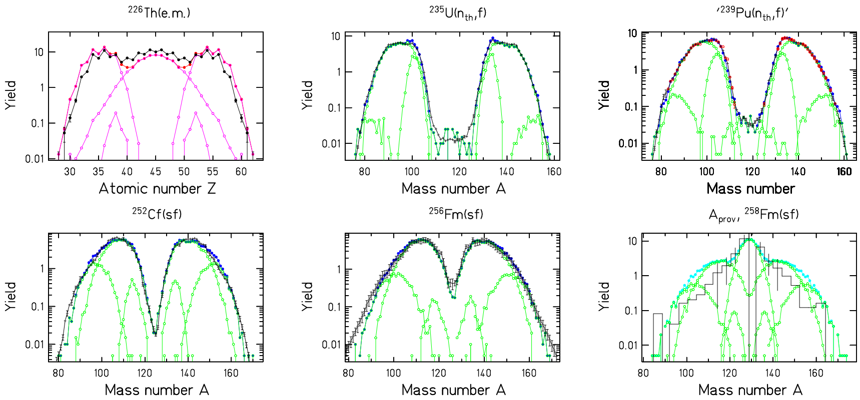

Figure 3: Nuclear-charge and post-neutron mass distributions of fission fragments. (For ^{258}Fm(sf) the provisional mass A_{prov} is shown, which is directly deduced from the ratio of the kinetic energies of the fragments and thus not corrected for neutron emission.) Experimental or evaluated data (black lines, respectively histogram) for electromagnetic-induced (e.m.), thermal-neutron-induced (n_{th},f) and spontaneous fission (sf) are compared with predictions of the GEF code [2] (red and green lines). The red symbols for ^{239}Pu(n_{th},f) show the experimental data behind the evaluation. The contributions of different fission channels are shown. (See [2] for references of the data.)

2.3 Separability principle

The microscopic-macroscopic approach has proven to be very useful for calculating nuclear properties, in particular in applications to fission [10]. The early influence of fragment shells on the fission path, deduced from two-centre shell-model calculations [11], makes its application to fission even more powerful. It means that the microscopic properties of the fission observables are essentially determined by the shells of the fragments, and only the macroscopic properties are specific to the fissioning system [12]. This separability principle was exploited in the GEF code [2], which relies on an empirical description of the macroscopic stiffness parameters in the relevant normal modes and empirically deduced fragment shells, which are valid for all fissioning systems. Figure 3 demonstrates that the mass distributions over a large range of systems can be described very well with the same parameter set. For a more complete overview see ref. [1].

2.4 Fluctuations

Most fission observables form bell-shaped distributions around a mean value. This suggests treating the corresponding collective degree of freedom as an harmonic quantum oscillator coupled to a heat bath of temperature T. Especially for the charge-polarization degree of freedom there exists a long discussion about the importance of the zero-point motion [16, 17]. Nix estimated the level spacing in the oscillator corresponding to mass-asymmetric distortions at saddle with the liquid-drop model to 1-2 MeV in the actinide region [18]. According to the smaller widths of the corresponding components to the mass distribution, the level spacing for oscillations in the two asymmetric fission valleys (Standard 2 and Standard 1) is expected to be even larger. Also for oscillations in the charge-polarization degree of freedom, the level spacing is in the order of 10 MeV [16, 17]. This value is appreciably larger than the temperature values of actinides, which are about 0.5 MeV in the constant-temperature regime [19]. Thus, in a statistical approach the charge-polarization degrees of freedom is essentially not excited, and also the widths of the fission channels in mass asymmetry are expected to be strongly influenced by the zero-point motion in low-energy fission.

Also the angular-momentum distributions of the fragments have been explained by orientation pumping due to the uncertainty principle [20] . Experimental indications for thermal excitations of spherical fragments [21] have also been explained by the compensation of the orbital angular momentum, which itself is induced by the zero-point motion [22]. Here it is the operator of the orbital angular momentum which does not commute with the angle that characterizes the direction of particle motion. Thus, all fragment angular momenta measured in low-energy fission [23] are explained by the quantum-mechanical uncertainty principle. There is no room for excitations of the angular-momentum-bearing modes [24].

Due to the strong influence of quantum-mechanical effects it is mandatory to explicitly consider these effects, as it is e.g. done in the self-consistent microscopic approach of ref. [25]. Stochastic approaches with classical models [26] may miss certain aspects of the fission dynamics.

2.5 Comparison with previous ideas

Several descriptions of the fission observables with applications of the statistical model have been proposed in the past. The present approach is rather close to the outline of a scenario proposed by Jensen and Dossing [27], although the present model covers a larger variety of observables. More importantly, it also tries to better exploit available empirical information.

Jensen and Dossing presented a statistical calculation of the mass distribution in fission with some ideas about the dynamics of the process. The most important modifications applied in the GEF code are: (i) The shell effects that were calculated from single-particle energy spectra in a Woods-Saxon potential with the Strutinsky method in ref. [27] are replaced by global fragment shells, which are adjusted to the measured mass distributions. The separability principle simplifies this task considerably, since the fragment shells are assumed to depend only on the fragment, and, thus, they are the same for all fissioning systems. (ii) The nuclear level density that was calculated from the same single-particle spectrum including pairing correlations using the BCS approximation in ref. [27] is replaced at low excitation energies by an empirical constant-temperature formula [19], which seems to be in good agreement with recent experimental results [28]. (iii) The influence of quantum-mechanics, in particular the zero-point motion, has been considered to model the distributions of collective coordinates. They are attributed to the motion of the quantum oscillators in their respective potential pockets perpendicular to the fission path. The parameters of these oscillators are deduced from experimental data. In addition, the shapes of the fragments at scission, the charge polarization, the angular momenta, and other properties of the fragments are calculated on the basis of similar ideas.

3 Prompt-neutron yields

3.1 Transformation of energy - the different contributions

In low-energy fission, the Q value of the reaction ends up either in the total kinetic energy (TKE) or the total excitation energy (TXE) of the fragments. The TKE is closely related to the distance of the centres of the two nascent fragments at scission, but, even if the pre-scission kinetic energy is neglected, the TKE cannot give information on the shapes of the individual fragments. The TXE, however, can be attributed to the individual fragments by a kinematical measurement of the prompt-neutrons. Still, there is no direct experimental information available on the processes, which are responsible for the transformation of part of the Q value into the excitation energies of the separated fragments. The situation is schematically illustrated in figure 4. Before scission, dissipation leads to intrinsic excitations, collective modes perpendicular to the fission direction (normal modes [18]) may be excited, and, finally, some energy is stored in deformation of the nascent fragments

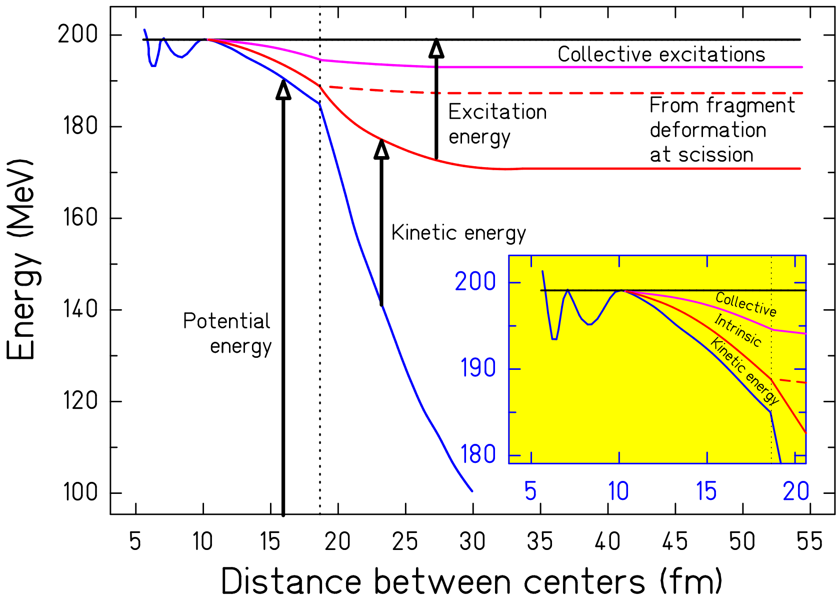

Figure 4: Schematic drawing of the transformation of energy during the fission process of an initial excitation energy equal to the height of the fission barrier.

that is induced by the Coulomb repulsion. The remaining part is found as pre-scission kinetic energy [29]. After scission, collective excitations and deformation energy are transformed and add up to the intrinsic excitations of the separated fragments.

The situation at scission is important for the understanding of fission dynamics, e.g. the magnitude of dissipation and the coupling between the different collective degrees of freedom, but without additional information, the repartition of the different contributions between the fragments remains ambiguous.

3.2 Origin of the saw-tooth shape

There is widespread agreement that the saw-tooth shape of the prompt-neutron yields, see figure 5, is caused by the deformation energies of the nascent fragments at scission. The scission-point model of ref. [8] attributes it to the influence of fragment shells, the random-neck-rupture model [30]

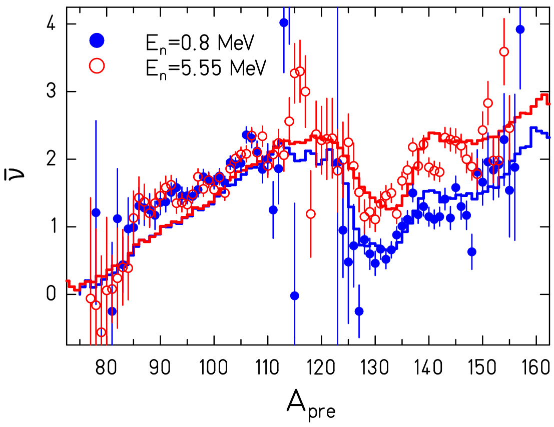

Figure 5: Measured prompt-neutron yield in ^{237}Np(n,f) as a function of pre-neutron mass at two different incident-neutron energies [32] (data points) in comparison with the result of the GEF code [2] (histograms).

links it to the location of the rupture, and also microscopic calculations predict large deformation energies of the fragments near scission [31]. Large even-odd effects in the fragment Z distributions indicate that the intrinsic excitation energy at scission is generally much too low to account for the variation of the prompt-neutron yield by several units over the different fragments.

3.3 Differential behaviour - energy sorting

Recent experimental results reveal that nuclei exhibit an essentially constant temperature, may be up to excitation energies of 20 MeV [28] with a temperature parameter that is grossly proportional to $A^{-2/3}$ [19]. This behaviour is explained by the breaking of pairs in the so-called superfluid regime [33]. This leads to a considerable increase of the heat capacity [34] and consequently to a slow variation of temperature as a function of excitation energy. Note that the BCS approximation severely underestimates the pairing condensation energy and consequently also the magnitude of the heat capacity in the so-called superfluid regime [35]. Thus, the assumption of a constant nuclear temperature becomes a good approximation. This implies that the intrinsic excitation energy of the two nascent fragments at scission is subject to energy sorting [36, 37, 38]: The hotter light fragment

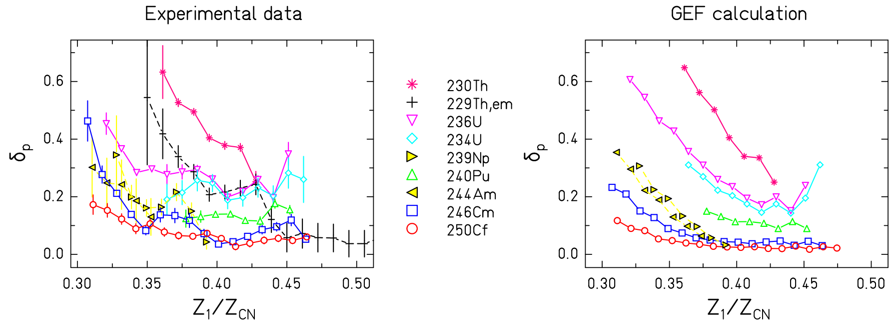

Figure 6: Measured (left) and calculated (right) local even-odd effect in fission-fragment Z distributions in (n_{th},f) reactions. The fissioning nuclei are indicated. Data for fission of ^{229}Th, induced by electromagnetic excitations are included. See ref. [39] for references of the data.

transfers essentially all its intrinsic excitation energy to the colder heavy fragment. This energy sorting manifests itself in the mass-dependent neutron yields. Figure 5 shows data for neutron-induced fission of ^{237}Np with $E_n = 0.8$ MeV and $E_n = 5.55$ MeV as an example. The additional initial energy leads to an increased neutron yield from the heavy fragments, only. The behaviour is well reproduced by the GEF code, which includes a model for the process of energy sorting.

4 Even-odd effect in Z yields

4.1 Experimental systematics

A systematic view on the local even-odd effect in fission-fragment Z distributions [39] reveals a regular pattern and a general dependence on the fissioning system, see figure 6. The magnitude of the even-odd effect is small at symmetry, and it increases strongly with increasing asymmetry. At the same time, the even-odd effect generally decreases for heavier systems. The even-odd effect in the light fragment group of nearby even-Z and odd-Z systems is essentially identical, except at symmetry, where the even-odd effect in odd-Z systems is exactly zero. Electromagnetic excitations lead to slightly higher excitation energies, thus reducing the magnitude of the even-odd effect. The large number of systems investigated revealed that the appearance of a large even-odd effect at large asymmetry is a general phenomenon, also in odd-Z fissioning systems [40]. In any case, there is an enhancement of even-Z fragments in the light fragment group, indicating that it is the enhanced production of even-Z light fragments in their ground state, which is at the origin of the large even-odd effect at extreme asymmetry.

4.2 Final stage of energy sorting

It seems straightforward to attribute the enhanced production of even-Z light fragments to the energy-sorting mechanism [41] that explained already the differential behaviour of the prompt-neutron yields. If the time until scission is sufficient for the energy sorting to be accomplished, the system can still gain an additional amount of entropy by predominantly producing even-even light fragments. Compared to the production of odd-odd light fragments, the excitation energy of the heavy fragment increases by two times the pairing gap, and its entropy increases due to the increasing number of available states in the heavy fragment. The right part of figure 6 shows a calculation with the GEF code, where this idea is included in a schematic way. The basic features are: (i) The excitation energy induced by dissipation grows with the Coulomb parameter $Z^2/A^{1/3}$, and the time needed for complete energy sorting is correspondingly increased. Also the energy gain from saddle to scission increases, and, thus the energy exceeds the constant-temperature domain. This explains the observed reduction of the even-odd effect for heavier systems. (ii) The temperature difference of the nascent fragments grows with increasing asymmetry, which enhances the energy-sorting process. This explains the strong increase of the even-odd effect at large asymmetry.

5 Charge polarization

5.1 Experimental information

Most experimental information on charge polarization at scission is indirect, because only the fragment masses after the emission of prompt neutrons can be measured with good resolution. Thus, the influence of prompt-neutron emission has to be corrected. This correction introduces some uncertainties, because most data on mass-dependent prompt-neutron multiplicities are not very precise, and for many systems such data are not available.

Figure 7 shows the measured deviation of the mean nuclear charge from the UCD (unchanged charge distribution) value for a fixed post-neutron mass and the standard deviation of the corresponding nuclear-charge distri-

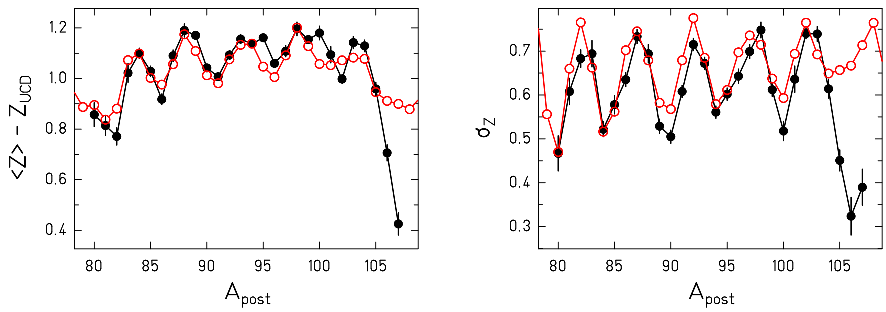

Figure 7: Indirect information on the charge polarization in ^{235}U(n$_{th}$,f). Left part:Deviation of the mean nuclear charge from the UCD (unchanged charge distribution) value for a fixed post-neutron mass A_{post}. Experimental data [42] (full points) are compared with the result of the GEF code [2] (open points). Right part: Standard deviation of the nuclear-charge distribution for a fixed post-neutron mass A_{post}. Experimental data [42] (full points) are compared with the result of the GEF code [2] (open points).

bution for the thermal-neutron-induced fission of ^{235}U [42]. The influence of the even-odd staggering of the Z yields is clearly visible in both quantities.

5.2 Simulation

The simulation of the nuclear-charge distributions for fixed post-neutron mass starts from the calculated pre-neutron nuclide distribution and the excitation energy of each individual fragment. The emission of prompt neutrons must be considered, which is constrained by measured mass-dependent prompt-neutron multiplicity distributions. The good agreement with post-neutron fragment distributions shown in figure 7 was obtained by minimizing the potential energy of the scission configuration, approximated by quadrupole-deformed fragments with a tip distance of 1 fm with respect to their N/Z ratios. However, for the asymmetric fission channels, the value of $< Z > -Z_{UCD}$ had to be increased (decreased) by 0.3 units in the light (heavy) fragment. This additional charge polarization may be attributed to the influence of the shell effects. The mean deformation of the fragments at scission is linked to the mean prompt-neutron multiplicity, considering the amount of intrinsic excitation energy at scission, which is consistent with the description of the even-odd effect in the Z distributions.

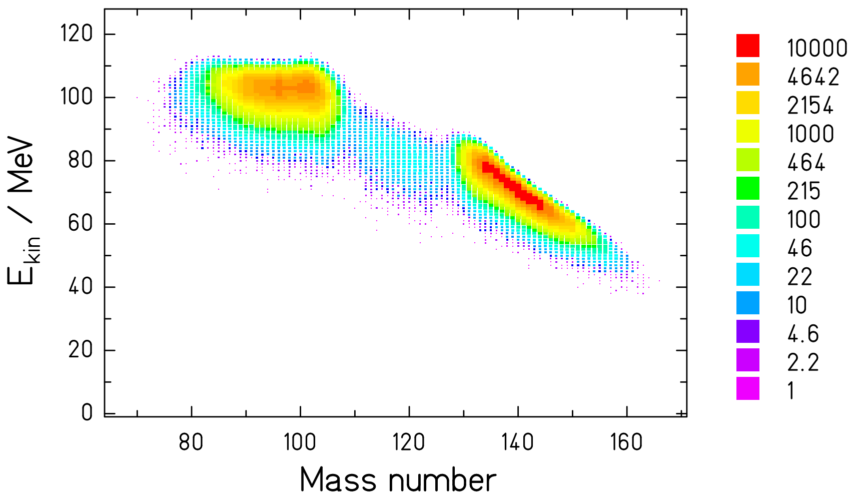

Figure 8: Two-dimensional distribution of kinetic energies and fission-fragment masses before emission of prompt neutrons for ^{235}U(n$_{th}$,f). The colour scale refers to the counts of the Monte-Carlo calculation with the GEF code.

6 Fragment kinetic energies

In the GEF code, the total kinetic energy of the fission fragments is given by subtracting the total excitation energy of the separated fragments from the sum of the initial excitation energy of the fissioning nucleus and the Q value of the fission process. The resulting distribution for ^{235}U(n$_{th}$,f) is shown in figure 8. The overall behaviour is in agreement with expectations from systematics. In the model, the shape of the energy distribution for a fixed mass is mainly defined by the distribution of fragment deformations at scission, which is taken as a Gaussian distribution with a maximum in the respective potential minimum. These shapes are assumed to be decisive for the amount of deformation energy of the separated fragments with respect to their respective ground state, which finally adds up to their intrinsic excitation energy. This explains the skewness of the distributions, which seem to be slightly larger than found in experiment.

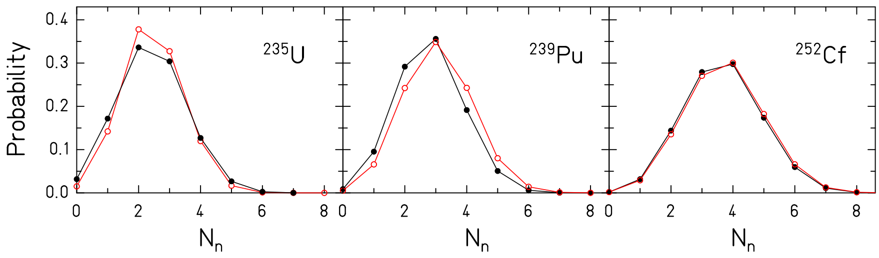

Figure 9: Measured prompt-neutron multiplicity distributions [43, 45] for ^{235}U(n$_{th}$,f) (left part), ^{239}Pu(n$_{th}$,f) (middle part) and ^{252}Cf(sf) (right part) are compared to the results of the GEF code (open symbols).

7 Neutron multiplicities

Besides the mass-dependent mean prompt-neutron yields, see figure 5, there exist two other experimental results, which have been determined with high accuracy: The mass-integrated neutron-multiplicity distribution and the mean number of prompt fission neutrons. The measured mean number of prompt-fission neutron yields is compared in table 1 with the values given by the GEF code for some selected systems. The same parameter set was used for all systems.

System	E_n	Exp	GEF
^{235}U(n,f)	thermal	2.41 [43]	2.47
^{235}U(n,f)	0.5 MeV	2.46 [44]	2.58
^{235}U(n,f)	5.55 MeV	3.19 [44]	3.38
^{237}Np(n,f)	0.8 MeV	2.73 [32]	2.63
^{237}Np(n,f)	5.55 MeV	3.46 [32]	3.43
^{239}Pu(n,f)	thermal	2.88 [43]	3.06
^{252}Cf(sf)	—	3.77 [45]	3.72

Table 1: Selected values of mean prompt-neutron multiplicities. The measured values are compared with the result of the GEF code.

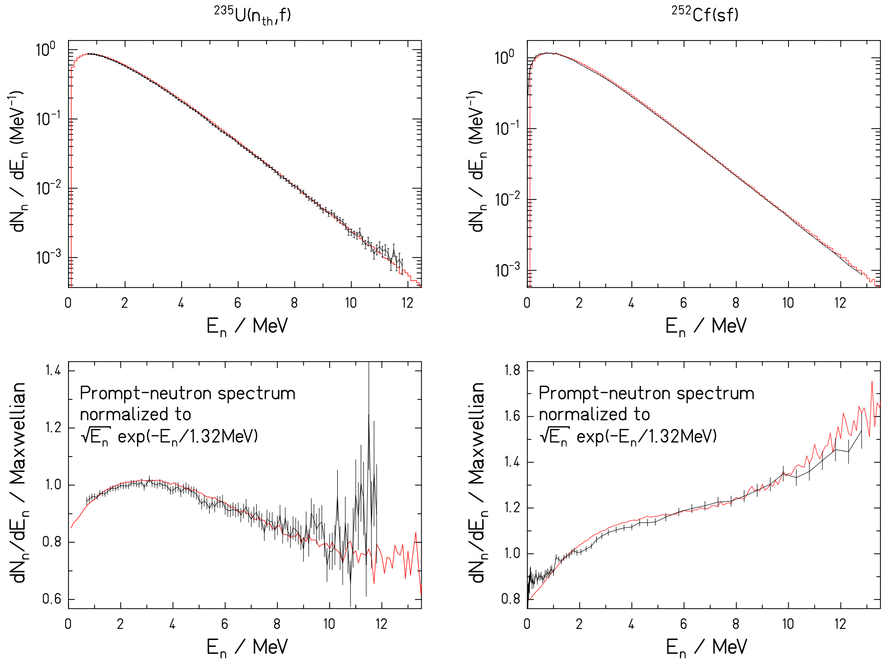

Figure 10: Experimental prompt-fission-neutron spectra (black lines and error bars) for ^{235}U(n$_{th}$,f) [46] (left panels) and ^{252}Cf(sf) [47] (right panels) in comparison with the result of the GEF code (red lines) in logarithmic scale. In the lowest panels, all spectra have been normalized to a Maxwellian with $T = 1.32$ MeV.

8 Prompt-neutron spectrum

The experimental prompt-fission-neutron spectra for the systems ^{235}U(n$_{th}$,f) [46] and ^{252}Cf(sf) [47] are compared with results of the GEF code in figure 10. In order to better visualize the deviations, the lower panels show a reduced presentation with the spectra normalized to a Maxwellian distribution with the parameter $T = 1.32$ MeV.

In this calculation, the de-excitation of the separated fragments has been obtained within the statistical model. It is assumed that both the emission of neutrons and the emission of E1 gammas does not change the angular momentum on the average, which seems to be a good approximation in the relevant angular-momentum range [48]. When the yrast line is reached, the angular momentum is carried away by a cascade of E2 gammas. The inverse neutron absorption cross section has been described by the parameterisation from ref. [49]. Since the fast-neutron spectrum in fission is composed of the contributions from many emitting fragments, the use of this global description that is computed very quickly is probably not too critical. Gamma competition at energies above the neutron separation energy was considered. The gamma strength of the giant dipole resonance (GDR) following the description proposed in ref. [50] was applied. The nuclear level density was modelled by the constant-temperature description of v. Egidy and Bucurescu [52] at low energies. The level density was smoothly joined at higher energies with the modified Fermi-gas description of Ignatyuk et al. [53, 54] for the nuclear-state density:

$$\omega \propto \frac{\sqrt{\pi}}{12\tilde{a}^{1/4}U^{5/4}} exp(2\sqrt{\tilde{a}U}) \qquad (1)$$

with $U = E + E_{cond} + \delta U(1 - exp(-\gamma E))$, $\gamma = 0.55$ and the asymptotic level-density parameter $\tilde{a} = 0.078A + 0.115A^{2/3}$. The shift parameter $E_{cond} = 2$ MeV $-n\Delta_0$, $\Delta_0 = 12/\sqrt{A}$ with $n = 0, 1, 2$, for odd-odd, odd-A and even-even nuclei, respectively, as proposed in ref. [55]. δU is the ground-state shell correction. A constant spin-cutoff parameter was used. The matching energy is determined from the matching condition (continuous level-density values and derivatives of the constant-temperature and the Fermi-gas part). Values slightly below 10 MeV are obtained. The matching condition also determines a scaling factor for the Fermi-gas part. It is related with the collective enhancement of the level density. The corresponding results are shown by the red full lines. The transformation of the neutron-energies into the laboratory frame was performed considering the acceleration phase [56, 57] after scission by a numerical trajectory calculation. The mean pre-scission total kinetic energy was assumed to be 40% of the potential-energy gain from saddle to scission derived by Asghar and Hasse [58] as

$$< TKE >_{pre} = 0.032(Z^2/A^{1/3} - 1527) MeV \qquad (2)$$

with a standard deviation of the same amount. The distribution was truncated at negative values.

The good reproduction of the measured neutron spectra, especially for the lighter system ^{235}U(n$_{th}$,f), does not give indication for neutron emission at scission [59, 60, 61, 62], although it is difficult to draw a definite conclusion due to the uncertainties in the level densities.

The emission during the acceleration phase is stronger for the system ^{252}Cf(sf), since higher excitation energies and, thus, shorter emission times

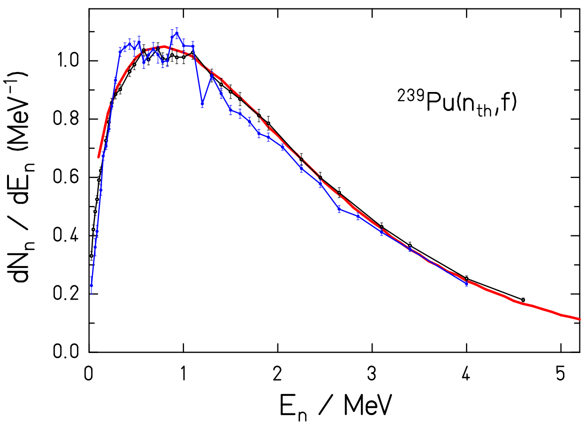

Figure 11: Experimental prompt-fission-neutron spectrum for the system ^{239}Pu(n_{th},f) from ref. [63] (black open symbols) and from ref. [64] (blue full symbols) in comparison with the result of the GEF code (red thick full line). The calculated spectrum was normalized to the measured total neutron multiplicity ($\bar{\nu}$ = 2.88 [43]). The measured spectra are slightly scaled for minimizing the overall deviations from the calculated spectrum in order to better compare the spectral shapes.

are involved in this system. Neutron emission during fragment acceleration reduces especially the laboratory energies of the first neutrons emitted at short times from the most highly excited fragments in ^{252}Cf(sf) and allows for a decently consistent description of the two systems with the GEF code, using the same parameter set. Experimental prompt-fission neutron spectra of the systems ^{239}Pu(n_{th},f) and ^{240}Pu(sf) are compared with the result of the GEF code in figures 11 and 12, again using the same model parameters. Obviously, the data are very well reproduced.

In general, the GEF code reproduces the available experimental fission-prompt-neutron spectra rather well. This qualifies the GEF code for estimating prompt-neutron spectra in cases where experimental data do not exist. The results of the GEF code for thermal-neutron-induced fission of several target nuclei are listed in the appendix I. More data can be generated by downloading the code [2] and by performing the calculations for the appropriate fissioning system. The code also seems to be a suitable tool for improving evaluations.

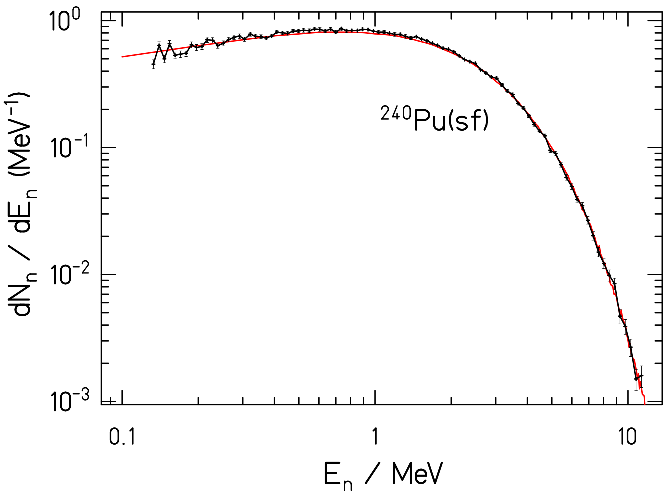

Figure 12: Experimental prompt-fission-neutron spectrum for the system ^{240}Pu(sf) from ref. [65] (black symbols) in comparison with the result of the GEF code (red line). The measured data were scaled to the height of the calculated spectrum. Since the experiment covers especially well the lower-energy range, a double-logarithmic presentation was chosen.

9 Correlations

Since the prompt-neutron spectra measured in the laboratory frame are the result of a convolution due to the emission under different angles from the moving fragments, they are not very sensitive to the yield of neutrons with very low energies in the frame of the fragments. Therefore, one may look for other experimental signatures that are more sensitive to specific features of the neutron emission. One of this signatures is the variation of the neutron multiplicity as a function of the angle between the directions of the emitted neutrons and the light fission fragment. Figure 13 shows the experimental data of ref. [66] in comparison with the result of the GEF code. The measured data are well reproduced over almost the complete angular range. The code underestimates the yield only very close to the direction of the light fragments. The two right-most points of the distribution correspond to angles of 5.7 and 9.9 degrees, corresponding to neutron energies in the fragment frame of 30 and 10 keV, respectively. Thus, these deviations can be explained by a slight underestimation of the neutron-absorption

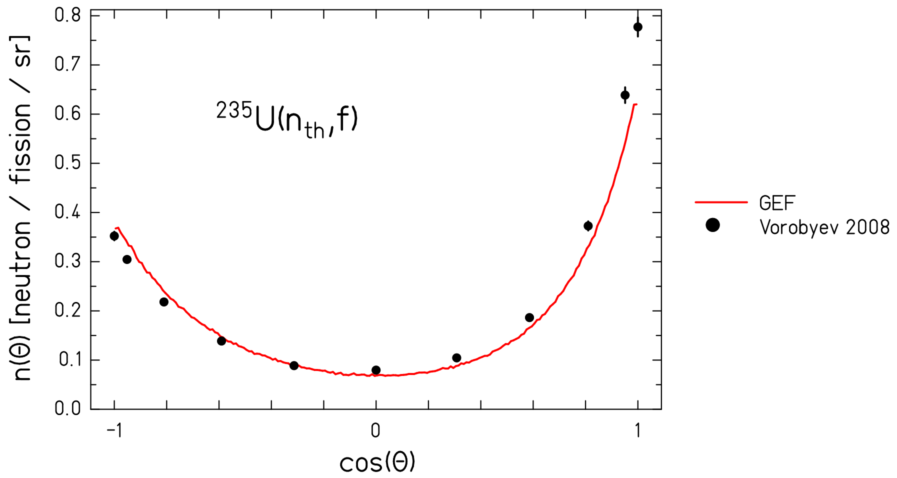

Figure 13: Variation of the prompt-neutron multiplicities versus the neutron direction relative to the light fission fragment. The result of the GEF code is compared with experimental data from ref. [66]. The nominal threshold in the experiment was 0.15 to 0.2 MeV.

cross sections in the very restricted low-energy regime below 50 keV. In the prompt-neutron spectrum, figures 10 to 12, these events appear at laboratory energies around 1 MeV due to the velocity of the emitting fragment. Here, no indication for this deviation can be seen. It seems that the description by the GEF code is very well suited for estimating the prompt-neutron spectra in the laboratory frame of heavy fissioning systems, which are most important for technical applications. The slight deviations in the angular distributions, figure 13, have practially no influence on the energy distribution of the prompt neutrons in the laboratory frame.

In the following we investigate the prompt-neutron yield as a function of the fission-fragment total kinetic energy. Figure 14 shows a comparison of the result of the GEF code with experimental data [67, 68] and a previous calculation of Kornilov [69]. The GEF calculation has been performed using Thomas-Fermi masses of Myers and Swiatecki [70] with recommended shell corrections and schematic even-odd fluctuations. The variation of the prompt-neutron yields from the light and the heavy fragment are assumed to be uncorrelated for a given split in Z and N.

The GEF calculation, in particular the slope, is rather close to the ex-

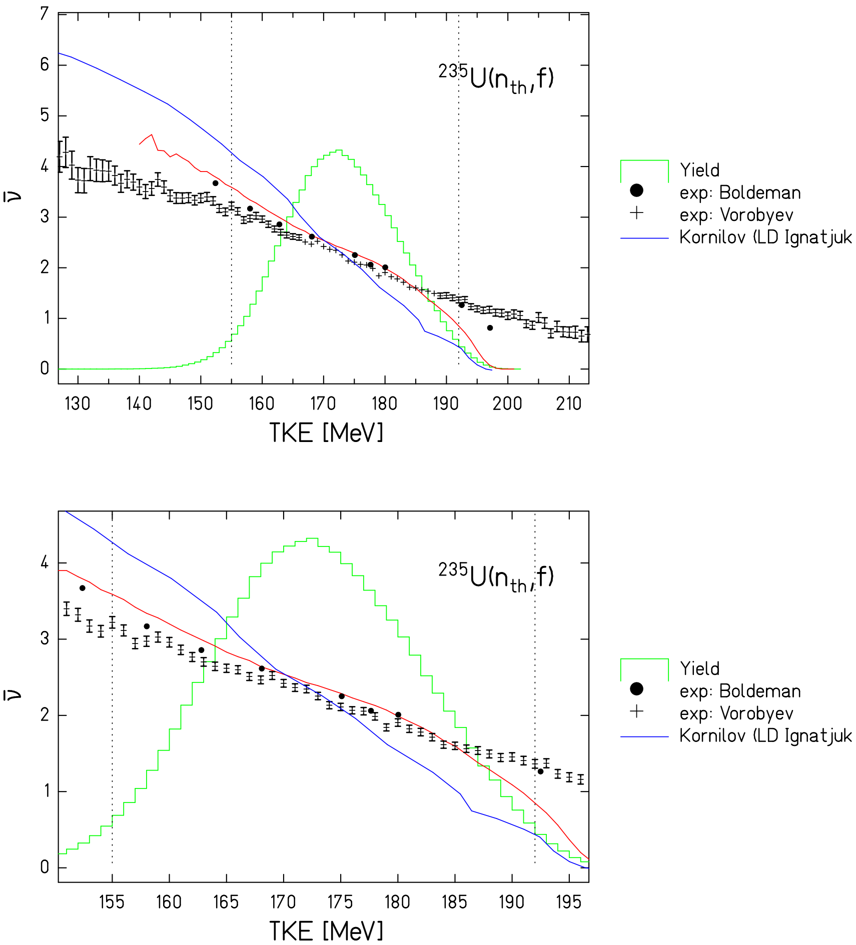

Figure 14: Mean prompt-neutron yield as a function of fission-fragment total kinetic energy for the system ^{235}U(nth,f). The experimental data of Boldeman et al. [67] and Vorobyev et al. [68] are compared with a calculation of Kornilov [69] (labeled as LD Ignatyuk) and the result of the GEF code (red line). The lower part shows a zoom on the central part of the TKE distribution. The green histogram shows the calculated pre-neutron TKE distribution in an arbitrary scale. The dotted vertical lines denote the region that contains 95 % of the fission events.

perimental data in the region between 155 MeV and 185 MeV. Also the low-energy point of Boldeman et al. is well reproduced. For energies higher than 185 MeV all calculations, also the calculation of Kornilov, are appreciably below the experimental data. The cut-off of the neutron multiplicity slightly below 200 MeV is probably realistic, because even for the splits with the highest Q values the excitation energies of the fragments fall below the corresponding neutron separation energy for these high TKE values.

One should not forget that scattering phenomena can considerably disturb experimental data in regions of low yield as e.g. demonstrated in ref. [71]. Such processes would tend to flatten the variation of the measured prompt-neutron yield as a function of TKE. In this context it is interesting to note that the data of Boldeman et al. have a steeper slope than the data of Vorobyev et al., especially in the wings of the TKE distribution. The data of Vorobyev et al. even extend to TKE values, where there is hardly any yield expected, and neutrons are still seen above TKE = 200 MeV, where neutron emission is suppressed in the GEF code due to the Q-value limit. This puts also doubts on the data of Vorobyev et al. for total kinetic energies below 150 MeV, where the yield is low, and scattering phenomena may have an important influence.

The GEF code reproduces also well the measured mean prompt-neutron yields as a function of the total fission-fragment total kinetic energy for spontaneous fission of ^{252}Cf of ref. [72], see figure 15. The deviations at high TKE appear in a region of extremely low yield. They may be explained by a background of events with lower TKE due to random coincidences of fragment and prompt-neutron signals. Also the deviations at low TKE appear in a region with low yield. They may be caused at least to a part by incompletely measured TKE values due to scattering phenomena in the experiment.

One may speculate that the transport of a multitude of correlations along the fission process in the GEF code without any intermediate averaging has an important influence on correlations between different fission observables. These correlations might not have been fully considered in other models. The calculations with the GEF code do not give strong hints for additional phenomena like scission neutrons; the data of figures 14 and 15 can rather well be reproduced with the assumption of prompt-neutron emission from the fragments after scission, only.

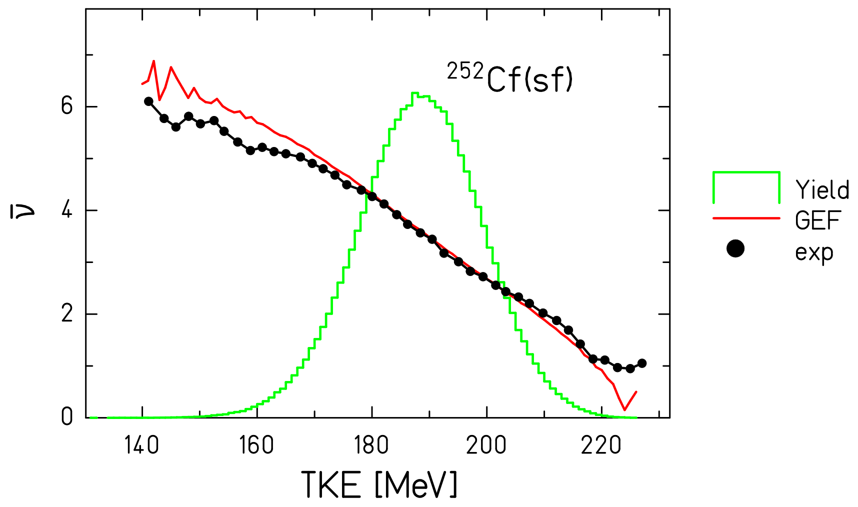

Figure 15: Mean prompt-neutron yield as a function of fission-fragment total kinetic energy for the system ^{252}Cf(sf). The experimental data of Budtz-Jorgensen et al. [72] are compared with the result of the GEF code. The green histogram shows the calculated pre-neutron TKE distribution in an arbitrary scale.

10 Conclusion

The semi-empirical fission model, implemented in the GEF code, reproduces a large variety of observables with a good precision in a consistent way without further adjustment to specific fissioning systems with a unique parameter set. With this global approach one is able to predict several characteristic quantities of the fission process, e.g. the energy and multiplicity distribution of prompt-fission neutrons, without the need for specific experimental information of the respective system, e.g. measured mass-TKE distributions. All properties of the fission fragments that are considered in the code (e.g. nuclear charge, mass, excitation energy, angular momentum) are sampled in the corresponding multi-dimensional parameter space by a Monte-Carlo technique. Thus, all respective correlations are preserved. Moreover, correlations between all observables considered in the code are provided on an event-by-event basis. The measured prompt-neutron spectra in fission induced by thermal neutrons are very well reproduced by the GEF code without any specific adjustment of the model for all systems that were investigated. It is to be expected that this agreement is preserved for fission induced by neutrons of higher energies. There are no systematic deviations which suggest the presence of scission neutrons in these cases.

Acknowledgment

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Appendix 1:

Table of prompt-neutron energy spectra for selected target nuclei in thermal-neutron-induced fission from a GEF calculation with 10^7 events. (ZT, AT: Z and A of target nucleus, nu: mean prompt-neutron multiplicity. The energy values mark the lower limits of the energy bins: 0.1 denotes the energy bin from 0.1 to 0.2 MeV, 0.2 denotes the energy bin from 0.2 to 0.3 MeV, and so on.)

ZT	90	90	90	90	90	90	91	91	91	91	91	91	92	92	92	92
AT	227	228	229	230	231	232	229	230	231	232	233	234	232	233	234	235
nu	1.842	1.756	1.867	1.821	1.967	1.870	1.936	2.209	1.986	2.218	2.061	2.252	2.176	2.448	2.256	2.468
E/MeV																
0.1	444324	426755	455220	448311	487077	469515	450668	510774	463826	520045	488860	535803	492915	550934	513683	561528
0.2	540910	521727	555930	544412	591977	570546	548624	621672	567519	634241	594689	651279	599111	669414	627286	683315
0.3	600267	577175	614775	604618	655925	631488	608866	689381	629654	700157	659776	723810	667622	745040	696467	760808
0.4	635802	612719	652253	640245	694446	669081	646644	734374	669485	746106	702405	767374	709157	792160	738806	808141
0.5	659341	634956	676617	664393	718746	692557	672936	762269	693522	774141	727414	794743	741150	822472	771112	840928
0.6	673702	646558	689549	676544	732917	703066	686543	780784	710271	791272	744939	813082	752561	842894	788794	859243
0.7	676112	649784	690993	679054	732768	702428	693770	785388	715114	797290	747641	816319	763204	849100	795500	867187
0.8	672919	646173	686161	672600	725381	696252	689380	784909	712130	793597	741792	811106	760599	849372	792824	865006
0.9	660105	631088	674421	659831	713009	680649	681468	775242	701643	783980	731746	798866	753524	841255	781419	853217
1	645182	616719	656482	642900	696090	661464	666680	760468	684786	767809	714149	782732	739238	826403	767858	838476
1.1	629319	602070	639392	623678	676654	641723	649853	741819	669210	749427	696350	762281	722347	807211	751805	819140
1.2	610401	582587	618527	604362	654938	620418	632528	722938	651451	726576	676875	742507	704170	787465	731380	798441
1.3	589076	563093	598268	583150	632604	599334	613345	700590	628819	704927	654471	717928	684444	766429	709157	776216
1.4	567253	541595	575499	560559	608049	574790	592337	678718	608426	681771	631113	692758	660690	741407	688676	750633
1.5	546887	520886	551850	538889	582061	551113	571075	653935	584720	655510	607113	667494	638593	716569	662026	724258
1.6	523011	497654	528351	515469	558757	525625	549515	627177	561238	630263	582926	637862	612781	689917	635789	696236
1.7	498572	474209	504928	490734	530694	501785	524969	602052	537337	603195	558098	612166	589799	662736	609574	668564
1.8	476913	451711	480124	466698	506112	477460	501867	574538	513548	574959	531859	582324	563236	633038	583389	638410
1.9	453759	429864	457193	443692	481149	453797	477916	547969	489683	548390	505976	554898	538968	605886	557273	609186
2	427855	408297	433375	420231	456132	428874	455102	521968	464604	522281	481226	527018	513031	579297	531711	581703
2.1	407843	388017	411004	398536	430767	405517	432289	497148	441726	496636	456854	502144	489016	552360	505508	553206
2.2	385612	366665	389169	378182	408444	384851	411240	470595	419162	471387	433134	476595	464701	525264	480229	526622
2.3	365733	346379	367122	356310	386455	364047	388826	446256	397319	445829	411670	450343	441239	498566	457445	499318
2.4	344691	328171	347735	337586	363944	342532	368678	422701	376290	423975	388363	426441	420353	473453	432824	475785
2.5	325756	308408	327671	318602	345581	323066	348628	400468	356824	399502	367315	401802	398013	448233	409195	449029
2.6	307542	291688	309353	300196	324849	305275	329114	378324	336668	377302	347024	381197	375543	424219	387381	424697
2.7	289628	274644	292215	282725	306010	287433	310704	357471	317579	356185	328119	358047	354872	401758	367538	401849
2.8	272846	258629	274494	265731	288193	270512	294374	337460	300667	335613	308417	339112	335193	379724	346705	380044
2.9	256204	243659	258221	251234	271485	255158	277167	316908	283308	316726	290893	318093	316636	356341	327314	358386
3	241316	227687	242642	236378	253732	238951	260169	299488	265886	298841	274376	298894	298488	337935	307456	337354
3.1	227394	215177	228423	220398	236920	224700	244931	282396	250286	280827	258560	281106	281513	319552	289779	318244
3.2	213811	201381	213865	207434	223804	211867	230238	264492	236294	263862	242505	264642	264237	300097	273617	299814
3.3	199949	190022	200650	194480	209924	198217	216527	249297	221145	246993	227899	249295	249314	282885	257108	283190
3.4	187699	177687	188261	183039	196886	185776	203623	234132	207426	232218	214688	233348	235002	266346	242457	265902
3.5	175416	166261	177160	170699	184906	174723	192099	218534	194666	218150	200713	218598	220118	249998	227115	250032
3.6	165459	156368	164654	160601	171918	163032	179905	206302	183777	203839	188394	204347	207243	235275	213445	234458
3.7	154742	146463	155204	150643	161519	152475	167471	193032	171480	191901	176265	191895	194158	221424	200255	220626
3.8	144811	136706	145482	141172	152030	143106	157579	180839	160832	179686	165665	179985	182604	206592	187745	206135
3.9	135217	128167	135212	131434	141508	134117	147936	169924	150726	168246	155203	167997	170695	194570	176485	193554
4	126043	119452	126812	123013	131657	124830	138456	159212	140578	157873	144524	158217	159976	182020	165139	181365
4.1	117955	111390	118999	114546	123652	117143	129186	148252	132329	147198	136140	146962	150668	170574	154790	169424
4.2	110108	104547	110953	107568	115764	109363	120763	138880	123515	137702	126831	137148	140276	160562	144345	158922
4.3	103520	97239	103650	100752	107403	101988	113118	128938	115035	127814	118438	128459	131556	149099	135347	147937
4.4	96531	90990	96727	93547	100525	95551	105802	121249	107918	119223	110540	119763	122684	140196	126578	138980
4.5	89384	85291	90285	87308	94213	89036	98924	112273	100475	111297	103343	111422	115135	130992	118244	129946
4.6	84235	79608	84222	81424	87592	83244	91423	105547	93475	104351	96343	103774	107419	122832	110624	121326
4.7	78284	74380	78729	76355	81305	77274	85914	98142	88001	96567	90217	97070	100282	114015	102763	113157
4.8	72729	68890	72907	70965	75748	72279	80792	91618	82048	89990	83870	90402	93140	106609	96993	106411
4.9	67482	64196	68041	66273	70667	67381	74994	84879	76398	84559	78052	84371	87473	99653	90011	98668
5	63097	60033	63403	61844	65867	62240	69439	78962	70937	78491	73029	78910	81755	92761	84114	91903
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5.2	54655	52417	55510	53345	56501	54461	60676	68496	62357	68572	63418	68104	70844	80756	72692	80408
5.3	51062	48340	50820	49336	52798	50614	56473	64312	57569	63527	58936	63485	66235	75610	67785	75048
5.4	47620	45008	47753	46069	49034	46909	52794	59612	53829	59129	55219	58883	61607	70370	63335	69541
5.5	44585	41728	44230	42579	46002	43970	49137	55326	49707	55164	51027	54492	57465	65866	58825	65006
5.6	41044	38969	41377	40476	42641	40772	45842	51560	46202	51154	47775	51071	53832	61514	55129	60261
5.7	38200	36254	38434	37253	39456	37496	42217	47963	42834	47476	44463	47491	49868	57172	50946	56611
5.8	35817	33770	35530	34466	36793	35128	39449	44754	40028	44250	40958	43928	46158	52958	47570	51932
5.9	32976	31573	33053	32221	34327	32577	36268	41483	37334	41062	38449	40783	43168	49339	44427	48312

6	30666	28702	31090	30016	31730	30535	34169	38636	34954	37817	35386	38007	40239	45820	41003	45245
6.1	28602	26807	28695	27937	29240	28326	31802	35822	32228	35142	33285	35477	37285	42355	38395	42121
6.2	26560	25028	26605	26016	27416	26566	29740	33346	30075	33039	30799	32780	34893	39696	35495	39615
6.3	24457	23346	24544	24009	25580	24425	27370	30798	27881	30314	28634	30464	32418	36984	33382	36697
6.4	23136	21296	22838	22543	23430	22610	25262	28692	26130	28139	26527	28367	30103	34184	31189	33857
6.5	20955	20218	21275	20717	21657	21071	23668	26359	23779	26121	24921	26275	27713	31951	28849	31213
6.6	19568	18884	19984	19363	20266	19733	22097	24488	22354	24281	23175	24435	26016	29865	26647	29029
6.7	18110	17091	18051	17914	18823	18047	20246	22707	20788	22149	21271	22470	24072	27749	24808	27400
6.8	16629	15841	17093	16188	17282	16828	18872	21031	19167	20881	19848	20914	22263	25727	23211	25231
6.9	15457	14859	15686	15149	16288	15596	17414	19592	17982	19543	18192	19228	20745	24098	21170	23597
7	14547	13557	14645	14204	14791	14325	16396	18175	16499	17951	16761	17700	19200	22138	19733	21643
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7.2	12577	11782	12361	12306	12802	12430	13853	15347	14227	15230	14848	15732	16719	19135	17075	18664
7.3	11490	10832	11580	11259	11729	11596	12888	14450	13310	14305	13829	14321	15642	17798	15719	17434
7.4	10774	10085	10716	10411	10911	10686	12125	13130	12364	13136	12461	13308	14487	16468	15036	16177
7.5	9780	9431	10061	9633	10234	9915	11337	12198	11349	12266	11770	12230	13300	15147	13600	14849
7.6	9167	8827	9163	8977	9455	9245	10328	11461	10647	11330	10880	11398	12611	14284	12684	14168
7.7	8432	7936	8602	8289	8666	8507	9690	10605	9845	10412	9826	10421	11523	13217	11836	13021
7.8	7854	7188	7808	7647	8028	7948	8810	9787	9021	9647	9252	9665	10522	12084	10977	12129
7.9	7333	6724	7368	7047	7447	7311	8202	8982	8531	8831	8656	9010	9751	11371	10081	11135
8	6826	6375	6644	6689	6900	6860	7615	8398	7785	8359	7927	8106	9177	10544	9306	10440
8.1	6323	6021	6312	5906	6282	6171	7227	7504	7189	7655	7429	7647	8321	9661	8467	9506
8.2	5721	5517	5837	5648	5838	5854	6577	7397	6720	7277	6706	7335	7929	8901	8093	8939
8.3	5379	5148	5240	5194	5474	5307	6132	6525	6073	6514	6206	6599	7297	8243	7405	8231
8.4	4953	4819	4964	4771	5036	4928	5668	6227	5720	5961	5822	6177	6607	7691	6925	7670
8.5	4643	4199	4607	4442	4684	4594	5179	5649	5305	5750	5507	5665	6253	7242	6462	6999
8.6	4340	3936	4214	3947	4351	4271	4748	5207	4911	5282	4947	5217	5733	6584	5995	6575
8.7	3891	3706	3831	3752	3947	3867	4348	4872	4442	4836	4684	4725	5350	6286	5560	6115
8.8	3566	3457	3615	3621	3654	3621	4156	4610	4102	4589	4382	4454	4900	5656	5217	5612
8.9	3263	3205	3275	3335	3340	3365	3814	4255	3977	4054	4042	4197	4533	5356	4751	5316
9	3093	2924	3096	3020	3171	3093	3504	3838	3571	3993	3638	3745	4190	4956	4413	4778
9.1	2905	2716	2763	2840	2974	2834	3285	3537	3335	3593	3385	3609	4027	4697	4121	4538
9.2	2596	2509	2656	2504	2578	2638	3041	3218	3106	3260	3215	3297	3544	4238	3783	4334
9.3	2405	2302	2494	2424	2386	2465	2799	2975	2873	3080	2922	3115	3405	3924	3429	3822
9.4	2168	2057	2274	2245	2297	2292	2569	2637	2551	2872	2682	2831	3158	3707	3285	3618
9.5	2062	1916	2051	2057	2179	2116	2351	2602	2510	2469	2513	2606	2933	3372	2978	3329
9.6	1955	1787	1923	1839	1936	1898	2272	2316	2219	2387	2325	2387	2722	3161	2862	3036
9.7	1765	1700	1789	1638	1803	1844	1989	2168	2120	2238	2183	2172	2502	2935	2571	2868
9.8	1593	1537	1670	1609	1761	1677	2008	2023	1882	2033	2041	2069	2301	2796	2371	2608
9.9	1535	1450	1459	1525	1546	1526	1770	1889	1813	1889	1875	1831	2120	2573	2219	2390
10	1382	1276	1374	1416	1397	1418	1669	1745	1672	1737	1719	1711	1942	2334	2043	2322
10.1	1265	1203	1306	1251	1293	1233	1511	1580	1529	1632	1602	1592	1852	2101	1874	2224
10.2	1218	1111	1249	1154	1228	1205	1405	1457	1508	1446	1531	1513	1734	1978	1783	1958
10.3	1076	1044	1104	1103	1148	1140	1271	1364	1322	1410	1373	1354	1559	1870	1598	1813
10.4	1023	985	999	942	1080	977	1207	1297	1168	1245	1263	1290	1465	1700	1522	1720
10.5	862	884	952	976	994	904	1106	1181	1164	1127	1136	1213	1363	1674	1324	1557
10.6	956	849	833	848	889	897	991	1076	1052	1101	1070	1124	1219	1624	1285	1492
10.7	828	761	785	769	765	827	971	1010	984	1026	1005	1069	1156	1386	1212	1361
10.8	754	732	776	696	725	752	882	888	861	926	892	939	1060	1306	1122	1280
10.9	694	607	684	641	695	727	857	814	784	853	848	906	966	1143	1046	1135
11	602	559	677	634	676	596	735	802	821	780	794	820	888	1087	887	1050
11.1	559	568	593	556	594	585	689	686	684	731	719	756	859	1010	902	999
11.2	497	526	581	509	505	600	681	708	689	679	651	722	772	948	831	954
11.3	487	468	539	448	526	529	557	643	581	608	667	648	705	810	795	846
11.4	453	411	453	423	506	482	585	586	568	549	543	567	660	804	678	753
11.5	404	373	439	424	455	425	525	533	517	563	532	529	656	674	672	710
11.6	393	370	383	392	435	384	456	459	493	510	476	514	610	683	612	687
11.7	321	323	345	343	382	329	427	465	414	482	481	484	535	637	565	620
11.8	333	329	329	303	330	344	389	403	369	432	458	450	516	577	558	577
11.9	348	292	289	302	306	302	388	391	356	424	354	379	510	533	504	544
12	281	281	298	282	310	289	344	355	361	395	339	378	453	506	440	499
12.1	229	215	255	267	259	271	315	305	309	348	355	329	411	489	412	442
12.2	219	224	248	278	277	254	285	279	280	310	310	333	390	438	399	445
12.3	235	193	221	221	203	201	240	316	265	312	265	292	332	416	369	408
12.4	207	201	203	238	209	210	247	235	274	244	279	277	324	332	356	351
12.5	188	171	193	186	199	188	237	263	233	233	239	206	286	359	328	358
12.6	171	169	182	169	175	182	245	206	204	245	233	240	254	322	296	321
12.7	141	154	162	158	172	187	189	215	195	194	200	199	259	321	236	270
12.8	158	150	151	127	135	142	178	209	194	214	193	196	235	275	240	275
12.9	125	116	135	127	136	148	157	156	179	170	180	180	227	214	250	243
13	122	107	115	113	124	129	146	157	149	177	156	159	216	226	230	254
13.1	108	112	118	98	129	107	156	166	136	182	140	167	192	245	188	224
13.2	100	105	114	85	112	108	132	152	159	136	151	149	168	187	171	191
13.3	95	98	93	93	96	107	127	136	134	127	138	151	157	184	176	204
13.4	87	93	96	106	93	78	105	126	107	101	135	111	149	158	132	165
13.5	95	79	93	101	94	65	96	108	107	125	111	108	127	151	131	170

13.6	69	68	90	79	78	82	69	111	102	103	102	123	113	141	118	142
13.7	66	80	81	60	85	84	86	99	92	86	105	108	119	121	118	133
13.8	72	54	72	83	63	61	80	83	72	80	91	90	94	132	91	113
13.9	45	57	72	70	66	78	59	70	80	79	79	81	100	112	101	136
14	57	57	60	54	59	64	71	76	68	71	83	73	94	115	108	109
14.1	42	53	56	51	50	70	58	71	78	73	85	85	100	106	97	105
14.2	47	36	38	38	54	50	48	57	60	60	56	51	73	103	73	70
14.3	38	49	44	40	43	46	54	58	48	70	42	64	57	76	84	80
14.4	47	37	30	53	36	46	43	51	52	53	53	66	66	70	64	92
14.5	34	35	36	40	45	38	49	44	40	58	47	63	59	79	63	62
14.6	23	34	38	36	33	45	39	55	51	54	31	64	69	76	68	65
14.7	39	34	37	31	42	39	53	34	45	55	48	45	50	83	65	70
14.8	38	31	18	27	24	34	40	38	36	41	35	45	57	65	67	57
14.9	27	22	42	25	34	34	34	29	41	26	34	38	34	43	43	62
15	27	24	28	19	20	27	31	24	34	41	30	32	51	59	39	44
15.1	27	21	19	17	27	15	27	25	40	23	29	26	33	46	31	44
15.2	18	23	23	24	22	22	18	31	27	34	31	31	42	48	45	50
15.3	11	15	17	11	26	18	24	31	32	23	36	22	32	46	51	40
15.4	16	13	20	25	13	19	21	26	34	28	21	24	41	37	42	37
15.5	14	14	15	14	13	21	19	17	24	26	29	18	20	32	31	21
15.6	12	15	11	15	12	15	28	22	12	12	24	17	30	24	25	34
15.7	12	12	20	22	14	16	20	21	15	15	23	22	26	35	37	31
15.8	9	9	18	14	13	18	14	27	18	14	18	19	23	24	22	32
15.9	10	13	5	17	11	12	14	13	17	23	27	18	23	27	21	26
16	15	18	9	7	6	13	13	19	14	15	17	12	20	22	22	24
16.1	12	8	8	10	11	17	11	17	9	16	10	8	12	30	12	24
16.2	7	11	5	13	9	10	9	12	8	12	24	16	18	19	27	14
16.3	13	8	9	17	10	9	6	12	12	11	10	13	17	11	19	18
16.4	10	10	15	8	12	6	12	12	14	12	6	10	19	17	10	27
16.5	8	11	12	9	12	9	7	11	10	12	11	11	7	14	16	13
16.6	6	12	5	3	6	8	7	6	10	12	6	10	19	21	12	15
16.7	4	4	5	8	3	8	9	8	8	11	10	13	9	12	16	18
16.8	7	6	4	4	5	9	4	6	8	9	10	5	11	17	11	16
16.9	4	5	6	4	6	2	9	9	8	8	13	10	10	9	13	13
17	2	3	5	5	6	8	6	6	14	3	7	9	7	16	9	12
17.1	3	6	2	4	6	8	2	4	8	8	7	10	9	10	14	12
17.2	5	3	3	9	4	7	6	3	6	7	9	5	3	12	6	7
17.3	3	4	2	3	5	7	6	2	4	4	7	10	14	10	9	6
17.4	1	6	6	1	5	8	2	4	5	3	7	8	4	6	8	6
17.5	6	4	3	3	3	4	3	3	3	6	6	7	9	4	5	9
17.6	2	3	6	1	1	3	5	2	4	8	5	7	5	8	8	8
17.7	3	2	4	5	4	1	3	5	1	7	2	7	5	9	7	7
17.8	0	1	2	3	3	1	5	3	0	5	6	4	3	8	4	5
17.9	0	1	4	0	0	2	2	1	3	5	4	3	3	7	4	8
18	2	6	2	2	1	2	0	2	2	4	6	2	4	6	5	3
18.1	4	1	6	0	0	5	1	1	3	2	4	4	4	2	5	5
18.2	3	0	0	3	1	3	3	1	1	4	2	0	3	2	1	4
18.3	2	1	2	2	1	4	3	4	3	4	2	3	1	4	3	3
18.4	0	2	1	2	1	1	1	1	2	1	2	0	2	4	1	5
18.5	2	1	4	1	2	3	2	0	2	0	0	3	7	2	2	4
18.6	1	0	0	3	3	1	1	2	4	4	4	2	0	6	5	1
18.7	3	0	0	1	1	3	1	1	2	1	3	2	2	2	0	2
18.8	1	2	3	0	0	0	3	2	2	0	0	3	0	2	0	2
18.9	0	0	2	0	0	0	1	3	3	2	2	2	2	3	4	1
19	1	1	0	0	0	3	2	3	2	2	3	0	1	2	1	0
19.1	0	2	1	1	3	0	1	4	0	1	2	5	2	0	3	2
19.2	1	0	1	1	1	0	2	0	0	3	2	1	2	2	1	3
19.3	1	1	1	1	0	2	1	1	3	1	1	0	2	2	1	3
19.4	0	0	1	4	1	4	0	0	3	0	0	1	2	2	3	1
19.5	1	1	1	0	3	1	1	0	1	0	1	0	1	0	0	1
19.6	0	2	2	0	2	0	0	0	1	0	2	1	0	2	2	1
19.7	1	2	0	1	0	0	0	1	0	0	4	1	0	3	1	0
19.8	0	0	0	0	2	0	0	0	0	3	0	0	1	3	0	2
19.9	0	1	1	2	0	0	0	1	0	0	0	0	2	0	2	2
20	0	0	1	1	1	1	1	1	1	0	1	0	0	1	1	2

ZT	92	92	92	92	93	93	93	93	93	93	94	94	94	94	94	94
AT	236	237	238	239	234	235	236	237	238	239	236	237	238	239	240	241
nu	2.338	2.529	2.450	2.648	2.744	2.462	2.744	2.499	2.817	2.622	2.762	3.014	2.794	3.059	2.881	3.162
E/MeV																
0.1	537327	581202	565980	614511	595016	538525	602235	551314	619802	581871	585992	639144	596414	652958	619156	675523
0.2	654746	708777	692280	748908	725122	657730	733967	672534	757306	711288	715450	780950	729278	796137	756005	825037
0.3	727307	786581	766726	833510	806465	733140	816725	749234	841736	790669	797676	868683	811031	886775	843023	917057
0.4	773987	834741	816668	883859	860453	779713	867817	798215	895999	841353	850327	925534	864532	946240	896813	979155
0.5	802435	867249	846420	918022	895371	813156	905745	828681	932057	875213	886136	964179	903882	985368	934082	1017429
0.6	819858	886460	865333	936036	917398	832164	927174	849437	953852	894748	908582	990243	923292	1010620	957018	1043800
0.7	828532	891810	869299	939292	929929	841086	938553	858996	964905	903698	919926	1003588	934507	1022288	968058	1057024
0.8	823575	890170	866312	936508	929670	841565	937277	858516	963613	901631	921821	1002229	938089	1022154	966841	1057577
0.9	812665	878949	854490	922907	922126	832919	926712	846866	953485	893594	916470	998772	929575	1016881	961424	1049349
1	799318	863659	837469	906865	909972	819786	913474	836604	941806	877999	905112	986196	917779	1004092	949499	1036708
1.1	780695	843251	820628	885497	892664	804480	896082	817427	920101	860056	887696	968586	900947	982839	929913	1017961
1.2	757880	821911	798278	860859	874621	786317	875683	798139	900452	839507	867881	947929	880102	961265	909592	995540
1.3	735275	796757	771190	835436	848623	765047	853552	775900	875273	812612	848560	924815	858500	937615	886955	970882
1.4	713085	767690	745084	806927	826977	741310	826360	751266	848960	788600	822807	897529	834600	913427	857960	941094
1.5	684710	742700	720002	776329	797763	716457	797883	726484	819001	763336	799702	869147	807404	883087	832211	912336
1.6	659002	711365	688475	745887	772670	690513	770165	700798	789899	733339	770479	839657	777481	851622	803251	879531
1.7	632025	683332	661034	714128	739399	665026	739133	672921	759122	705925	742016	809096	748909	820695	773940	847507
1.8	605304	652320	630874	682653	711380	636964	712909	644377	726612	675197	712527	777635	720546	788920	741921	813674
1.9	577061	624050	602879	652360	682744	610345	680749	618327	697107	644930	684919	746508	690102	757395	711415	781090
2	549291	594179	574507	619851	651270	582347	649987	588990	665055	617125	654189	713783	661336	725354	681565	747060
2.1	522542	565123	545627	589280	623152	556618	619681	562478	635269	587034	625810	682839	631218	693605	649522	714414
2.2	496585	538662	518743	560702	593642	528682	590062	534569	606276	559782	596503	652739	602266	660962	619157	681504
2.3	470833	509389	492127	531199	565561	503849	563170	509286	574440	532583	568797	622373	574273	630512	590479	650649
2.4	447979	484207	466503	504674	537823	477988	534577	483767	547346	506463	540681	592309	547245	598548	562284	618211
2.5	422632	459198	443042	477339	509467	454682	507329	458630	520102	480233	516020	562864	520303	570325	535261	587471
2.6	401697	433028	418056	451221	483990	430105	480910	435442	491627	455266	490903	535546	492586	542024	506813	558655
2.7	379389	410428	394807	426457	457070	407188	456086	411835	465550	431569	464289	509026	467895	513479	481507	528930
2.8	357427	385745	373113	404559	434512	386410	430326	389684	440725	407487	439830	481691	442742	485999	456066	502767
2.9	337342	365623	351939	379974	410557	365851	408020	369695	416517	385538	416566	455828	420904	460612	432044	476410
3	317152	344735	332274	357720	386927	344203	384429	348571	394460	364083	394638	431026	395030	435879	408957	448141
3.1	298940	324865	312584	336697	366958	326710	364201	328021	372153	342387	372807	406180	375753	411593	386683	424776
3.2	281200	305490	294172	317617	345655	306612	342623	309351	350431	324150	351619	384745	353882	388900	364486	402413
3.3	266133	287037	276300	297888	324851	289541	323659	291521	330657	305466	332719	363758	334306	367553	344607	379983
3.4	249028	270047	260238	280486	307190	272592	304357	275479	310949	287251	314284	342096	316017	346080	322561	358194
3.5	233830	254120	242962	263816	288977	257064	286521	260165	292700	270393	295233	322623	297268	326084	305612	336335
3.6	219584	238942	228717	247705	271743	240698	267914	243959	275228	253411	278761	305278	280382	307208	287707	317528
3.7	206338	222852	215222	232852	255988	226452	253762	229024	259405	238596	261437	285891	263358	289123	270188	298957
3.8	193727	209332	201788	217089	239855	212693	236355	215670	243357	224746	247240	269099	248347	271073	254688	281749
3.9	181440	196592	188602	203904	224948	200077	222331	202084	227718	210910	231037	253202	232787	255867	239189	263926
4	169423	184096	176761	190421	211486	187775	209209	189842	213819	197588	217827	238282	220376	240761	223921	248247
4.1	159012	172611	165722	179538	197870	176498	196292	177713	200973	185991	204800	223032	205297	224972	210409	232751
4.2	148938	160955	154927	166888	186143	165252	183434	166792	188013	174180	191516	210408	193189	211483	198234	219764
4.3	139140	150484	145420	156929	173744	155023	172142	156354	176422	163170	179789	196842	181066	198870	185875	205284
4.4	130349	141235	136361	146258	163405	145152	161082	146104	165691	152816	168689	183822	169689	186221	174142	192315
4.5	122145	131582	126971	136431	152709	136010	150707	136406	154959	143579	157935	172938	158272	175056	163726	180678
4.6	114105	123510	117982	127986	142591	126893	141194	128356	145113	133917	147469	162194	149403	162810	153677	169457
4.7	106633	114708	111163	119179	133042	118756	131666	119768	135439	125185	138387	151667	139513	152903	142715	158252
4.8	99276	107925	103643	111105	124888	111048	122901	112276	126256	116915	130661	142791	131227	142972	134143	149075
4.9	92323	99489	96474	103579	116612	104160	115724	104908	118219	109108	122041	133113	122677	134135	124510	138811
5	86560	93071	90258	96922	109388	97036	107664	98570	110583	102359	114029	124720	114409	125450	117627	130184
5.1	80689	87078	83895	90472	101962	90079	100266	91290	102670	95548	106430	116257	107385	117488	109500	121633
5.2	74823	81033	78079	84408	95208	84765	93662	85333	96039	89880	99585	108242	100144	109387	102418	113800
5.3	70271	75791	72791	78717	88667	78894	87412	80230	89800	82532	93078	101816	93633	102366	95880	106781
5.4	65402	70718	67427	73300	82325	73990	81692	74652	83728	78405	87004	94998	87087	95902	89685	99324
5.5	60919	65806	63715	68442	77168	69118	75987	69455	77717	72265	81122	88580	81907	89494	83782	92019
5.6	56474	61318	59112	63454	71758	63641	71405	64753	72957	68114	75519	82662	75957	83428	78053	86518
5.7	52721	57491	55111	59310	66869	60008	65735	60345	68200	63467	70878	77251	71631	77874	72976	80875
5.8	48923	52715	51105	54686	62405	55837	61298	56632	63081	58865	65617	72073	67058	72190	68023	75559
5.9	45454	49357	47617	51385	58322	51716	57554	52710	58535	54948	61744	67615	62152	67766	63683	70642
6	42415	45938	44791	47692	54312	48433	53397	48938	55025	51130	56992	62854	58077	63281	59520	65569
6.1	39590	42818	41171	44124	50330	44863	50163	45606	51463	48098	53269	58514	54206	59335	55613	61566
6.2	36869	39761	38451	41366	47325	41862	46096	42439	47814	44803	49923	54590	50223	55029	51697	57333
6.3	34030	36867	35800	38360	43399	38808	42988	39767	44084	41595	46499	50780	47028	51228	47998	53309
6.4	31688	34170	32988	35622	40597	36372	40260	36905	40966	38625	43609	47414	43843	47607	44896	50020
6.5	29527	31921	30934	33121	37878	33975	37605	34008	38317	36213	40346	44195	40930	44701	42167	46403
6.6	27456	29858	28899	30743	35168	31831	34843	32341	35721	33296	37520	41331	37865	41307	39454	43531
6.7	25345	27869	26670	28556	32713	29448	32599	29924	33363	31262	35357	38730	35442	38587	36087	40513
6.8	23590	25419	24890	26922	30439	27248	29986	27618	31095	29144	32563	35634	33094	36026	34134	37752
6.9	21826	23648	23137	24384	28464	25432	28062	25537	28710	26730	30339	33477	30877	33323	31485	34866
7	20397	22037	21605	22996	26078	23709	25859	24166	26881	25290	28612	30765	28776	31332	29428	32856
7.1	19112	20600	19855	21402	24261	21916	24089	22385	24949	23276	26767	28946	26427	28848	27349	30415
7.2	17554	19278	18488	19763	22678	20722	22635	20598	23012	21636	24475	26598	24829	27025	25628	28778

7.3	16415	17793	17234	18396	20986	18747	21140	19386	21620	20323	22992	24853	23073	25270	23814	26475
7.4	15222	16339	15817	17034	19750	17479	19172	18051	19845	18877	21114	23620	21569	23384	21912	24791
7.5	13973	15254	14572	15691	18064	16392	18210	16948	18655	17618	19885	22015	20190	21808	20608	23363
7.6	13009	14153	13725	14642	17102	15335	16865	15407	17653	16182	18421	20328	18871	20222	19160	21352
7.7	12135	13186	12653	13523	15828	14110	15560	14325	16062	14955	17499	18928	17407	19105	17655	20008
7.8	11111	12054	11783	12812	14721	13341	14226	13420	14934	13973	15852	17490	16358	17497	16756	18616
7.9	10381	11348	11143	11561	13305	12364	13359	12374	13880	13091	15100	16145	15081	16449	15397	17455
8	9735	10550	10379	10826	12423	11506	12478	11629	12952	12200	13781	15168	14066	15091	14481	16154
8.1	9170	9754	9450	10137	11665	10437	11771	11039	11808	11344	12882	14254	12981	14247	13432	14962
8.2	8427	9193	8855	9529	10814	9682	10661	10053	10965	10413	12126	13172	12022	13274	12518	13884
8.3	7692	8442	8218	8796	10050	9144	9996	9229	10266	9825	11053	12293	11278	12193	11671	13110
8.4	7072	7853	7470	8009	9184	8291	9369	8695	9636	9204	10356	11403	10651	11435	10612	12335
8.5	6664	7242	7076	7516	8667	7872	8537	8032	8848	8565	9793	10525	9766	10681	10234	11304
8.6	6204	6586	6544	7003	8022	7207	7826	7495	8323	7849	8907	9980	8994	10057	9449	10450
8.7	5764	6207	6039	6489	7419	6856	7407	6741	7696	7318	8316	9171	8436	9326	8807	9867
8.8	5282	5759	5532	6033	6952	6291	6926	6517	7199	6907	7793	8442	7940	8397	8000	9140
8.9	4946	5258	5178	5483	6504	5924	6342	5954	6599	6374	7319	7906	7413	7989	7651	8577
9	4592	4823	4770	5109	6030	5410	5865	5577	6276	5898	6651	7350	6761	7496	7066	7909
9.1	4203	4570	4440	4752	5490	4994	5334	5184	5767	5361	6378	6767	6188	6825	6535	7355
9.2	3790	4209	4302	4338	5278	4776	5296	4832	5331	5253	5735	6291	5896	6358	6189	6805
9.3	3633	3987	3836	4229	4594	4295	4719	4491	4938	4734	5414	6061	5542	6042	5587	6352
9.4	3340	3773	3543	3938	4360	4047	4358	4043	4456	4415	5041	5515	5023	5607	5325	5964
9.5	3076	3312	3309	3527	4076	3819	4071	3831	4334	4025	4551	4960	4833	5170	4804	5424
9.6	2988	3195	3079	3210	3753	3467	3778	3567	3986	3727	4413	4790	4429	4825	4600	5206
9.7	2669	2882	2895	3152	3608	3219	3510	3377	3701	3574	3973	4306	4125	4526	4192	4753
9.8	2501	2757	2645	2817	3267	2956	3283	3127	3484	3301	3690	4101	3835	4165	3995	4467
9.9	2287	2477	2471	2608	2929	2801	3013	2793	3064	3132	3437	3742	3576	3823	3586	4209
10	2164	2334	2382	2493	2759	2557	2781	2678	2905	2863	3313	3575	3299	3485	3442	3823
10.1	1925	2202	2164	2278	2640	2341	2605	2470	2780	2604	3062	3316	3045	3322	3263	3556
10.2	1857	1964	2018	2108	2393	2159	2406	2279	2527	2421	2759	3023	2828	3116	2964	3297
10.3	1683	1900	1802	1959	2265	2011	2208	2024	2331	2299	2711	2934	2639	2956	2794	3112
10.4	1565	1659	1689	1880	2049	1858	2134	2016	2227	2098	2419	2674	2525	2753	2537	2906
10.5	1535	1565	1589	1701	1963	1717	1864	1833	2013	1995	2213	2514	2308	2537	2381	2656
10.6	1348	1514	1431	1535	1801	1692	1867	1653	1964	1854	2131	2234	2144	2336	2222	2575
10.7	1324	1373	1311	1392	1611	1517	1651	1604	1784	1704	1937	2113	2041	2161	2053	2337
10.8	1150	1274	1251	1323	1479	1384	1541	1430	1594	1574	1862	2055	1838	2010	1875	2162
10.9	1047	1189	1132	1225	1406	1428	1439	1377	1527	1489	1682	1790	1697	1868	1916	2081
11	999	1067	1120	1145	1283	1174	1326	1289	1408	1368	1607	1780	1572	1756	1642	1903
11.1	949	1034	1019	1063	1225	1154	1254	1173	1325	1301	1529	1625	1531	1690	1533	1854
11.2	835	960	955	982	1093	1015	1102	1138	1184	1176	1397	1513	1434	1495	1494	1693
11.3	835	849	889	901	1028	978	1054	1014	1081	1147	1210	1320	1293	1398	1341	1510
11.4	728	806	778	891	1010	874	1051	943	1027	999	1177	1234	1214	1321	1308	1464
11.5	651	798	772	802	941	832	872	814	970	949	1065	1191	1106	1166	1166	1281
11.6	613	662	664	768	847	774	803	844	901	890	998	1062	1021	1110	1104	1129
11.7	591	619	629	680	798	725	803	716	860	799	945	1052	1023	1036	1043	1258
11.8	547	626	586	579	727	688	720	690	750	750	867	992	863	972	952	1086
11.9	530	542	560	572	677	593	683	656	700	709	822	909	819	855	873	1034
12	466	543	533	526	666	588	628	645	697	642	731	774	849	824	842	899
12.1	460	448	486	496	588	539	588	598	627	614	732	778	693	836	761	814
12.2	379	429	477	470	498	495	540	564	587	534	635	685	683	747	697	815
12.3	389	403	425	439	527	488	515	505	547	531	643	660	606	677	687	719
12.4	338	382	379	407	439	469	460	472	545	528	569	658	573	622	572	715
12.5	302	340	299	401	417	405	428	418	436	448	544	570	519	584	601	666
12.6	286	342	343	326	390	375	413	391	448	393	462	540	514	564	524	598
12.7	260	330	283	333	361	329	368	349	415	370	445	508	475	519	430	530
12.8	279	283	247	290	349	316	301	353	336	389	423	446	457	430	492	490
12.9	233	311	240	281	300	302	326	302	339	351	406	447	387	412	417	488
13	240	236	238	291	281	284	331	295	311	320	334	410	374	405	357	426
13.1	228	226	210	249	277	279	268	233	320	279	349	380	367	370	366	417
13.2	173	198	198	225	245	223	264	270	257	277	317	377	324	393	382	369
13.3	171	208	202	202	242	211	244	255	249	259	318	318	305	352	337	382
13.4	160	177	159	212	218	211	200	244	240	245	260	292	305	319	302	360
13.5	150	165	136	167	217	179	222	208	213	231	250	297	255	298	288	332
13.6	150	152	162	166	175	165	157	180	205	210	245	269	243	241	227	309
13.7	114	157	140	166	201	180	172	168	209	181	230	237	227	242	245	281
13.8	131	135	147	153	177	134	185	168	159	174	210	218	205	244	229	271
13.9	97	122	119	121	143	148	144	167	189	173	209	213	185	193	221	235
14	102	119	116	134	146	130	134	135	148	136	183	210	200	197	195	221
14.1	97	94	108	119	122	137	121	118	121	122	169	193	180	186	176	212
14.2	109	102	88	117	111	116	116	117	133	158	151	152	151	167	161	184
14.3	87	98	86	100	130	122	112	95	114	122	121	154	157	148	151	177
14.4	77	97	81	81	106	110	110	100	115	106	140	136	128	139	143	185
14.5	65	77	87	88	92	94	83	107	116	102	115	147	141	133	127	160
14.6	63	67	68	79	85	86	92	88	92	93	104	148	133	128	116	168
14.7	57	62	55	70	66	70	94	91	85	96	99	114	111	133	110	138
14.8	51	59	66	59	86	62	71	79	72	82	99	119	92	136	135	140

14.9	50	64	41	74	77	67	66	73	75	81	74	102	107	94	103	106
15	49	54	61	63	55	58	67	70	71	67	90	94	94	89	100	97
15.1	36	51	53	45	61	56	47	58	73	63	80	81	80	71	83	112
15.2	54	47	47	51	59	40	52	54	78	49	72	92	63	96	75	98
15.3	34	44	51	47	61	53	50	65	59	63	70	75	78	86	91	102
15.4	39	52	34	45	49	44	54	48	49	51	57	89	64	72	62	77
15.5	31	35	27	50	42	50	52	46	52	57	61	74	55	72	62	85
15.6	30	32	39	37	46	41	60	41	43	41	49	54	64	72	45	69
15.7	32	33	29	47	32	36	38	48	41	46	48	74	53	48	61	63
15.8	36	29	38	24	46	37	32	37	48	60	61	45	45	44	67	47
15.9	19	33	31	32	28	38	35	34	48	40	52	47	46	54	41	49
16	25	18	31	26	28	25	35	27	32	34	45	57	48	49	58	53
16.1	21	17	20	28	24	27	21	26	35	43	31	39	37	34	43	53
16.2	22	22	13	23	26	25	27	22	33	27	38	38	45	42	34	52
16.3	18	16	18	18	19	20	20	17	28	34	35	36	36	45	25	54
16.4	12	13	18	13	15	20	18	20	20	29	29	46	32	39	24	33
16.5	14	17	13	23	22	24	19	34	23	23	21	28	32	33	32	35
16.6	8	18	14	23	21	17	17	19	24	8	30	20	28	39	26	29
16.7	12	15	19	19	14	21	28	20	26	17	26	36	29	25	30	25
16.8	14	10	10	22	16	15	14	13	24	15	18	29	24	41	23	28
16.9	11	10	19	13	10	14	15	14	20	22	18	22	20	19	20	26
17	20	10	13	17	18	11	21	13	13	17	15	17	20	23	26	37
17.1	12	10	18	8	13	16	9	7	20	22	12	26	19	23	26	24
17.2	10	11	9	11	12	12	16	11	8	12	17	20	23	17	13	16
17.3	10	14	6	19	11	15	15	14	15	11	19	14	8	14	19	13
17.4	11	5	13	7	7	13	7	12	8	13	12	17	12	15	11	20
17.5	4	13	9	12	9	9	11	12	11	14	8	10	9	15	20	18
17.6	11	5	9	6	11	11	15	11	7	13	12	15	11	14	6	20
17.7	5	3	7	7	5	7	11	13	11	11	14	10	13	20	12	18
17.8	8	10	7	13	7	6	8	11	6	11	11	19	14	14	12	13
17.9	6	11	8	10	4	6	6	6	8	14	14	12	13	7	10	15
18	8	8	5	4	5	6	9	9	8	7	8	3	13	14	12	11
18.1	4	3	2	5	6	7	6	6	5	4	10	14	9	15	11	7
18.2	5	4	4	4	6	5	5	4	4	6	5	6	8	7	10	9
18.3	7	6	8	3	4	6	2	8	5	9	3	16	8	5	8	11
18.4	3	7	3	6	5	5	6	1	6	3	4	7	7	7	11	11
18.5	3	4	4	5	2	5	5	4	8	3	7	8	9	6	9	11
18.6	2	0	4	6	1	2	4	5	3	8	2	5	9	5	10	9
18.7	2	3	0	1	2	1	3	2	4	6	3	8	7	3	7	8
18.8	3	5	2	3	3	3	1	1	5	6	5	5	6	10	4	11
18.9	0	5	6	2	6	4	3	5	6	2	2	5	4	8	6	10
19	1	3	4	4	4	4	2	1	5	3	5	5	4	6	8	5
19.1	4	4	5	1	3	1	1	4	3	5	2	4	4	4	6	7
19.2	2	0	3	1	4	3	2	4	0	8	5	3	4	2	6	6
19.3	7	2	1	2	2	1	6	1	1	4	3	5	0	6	3	4
19.4	0	0	3	2	1	3	2	2	1	5	3	5	5	3	3	6
19.5	1	2	5	2	1	0	2	2	5	3	0	3	3	3	5	3
19.6	0	3	3	1	5	2	2	1	2	2	6	3	4	2	1	4
19.7	1	2	1	2	4	2	5	0	1	4	2	1	1	6	1	0
19.8	2	2	1	3	0	5	0	3	3	0	3	3	2	4	2	3
19.9	0	1	1	1	2	3	1	4	5	1	1	3	5	2	0	6
20	2	1	1	2	1	2	0	1	2	2	1	3	2	3	0	1

ZT	94	94	95	95	95	95	95	95	96	96	96	96	96	96	96	96
AT	242	243	239	240	241	242	243	244	242	243	244	245	246	247	248	249
nu	2.994	3.266	3.033	3.289	3.098	3.386	3.203	3.510	3.412	3.650	3.452	3.761	3.550	3.877	3.647	3.973
E/MeV																
0.1	646985	705533	627900	680033	646958	706972	676259	744138	699721	744842	718150	780769	750029	819649	784579	855402
0.2	791741	861918	768111	831175	791174	863307	828283	907593	851465	911671	874215	951417	915199	997382	957182	1040376
0.3	880355	959157	855075	926011	879936	961026	922301	1010715	949198	1014671	975857	1059840	1017637	1110014	1063528	1157580
0.4	939178	1021370	911959	987421	939667	1026571	981327	1078974	1013900	1081940	1038204	1131009	1084763	1183796	1132967	1233719
0.5	975313	1061698	952338	1029897	979094	1069510	1020638	1124507	1057443	1128234	1080383	1180644	1130008	1232108	1177561	1282810
0.6	999075	1088643	975933	1056576	1005377	1095939	1048920	1149448	1084980	1160863	1111835	1210409	1158185	1264893	1205507	1313892
0.7	1009338	1098694	991594	1071067	1018720	1108852	1059530	1164173	1098216	1175215	1124310	1224468	1172522	1279785	1219844	1331013
0.8	1011556	1100680	993537	1076306	1020673	1112455	1061890	1166338	1106816	1183022	1129894	1230446	1176086	1282625	1224918	1331148
0.9	1001315	1090793	988688	1067695	1016203	1106958	1056586	1158528	1101652	1174766	1124435	1222990	1167169	1275070	1215192	1322894
1	987522	1076547	975470	1057692	1003103	1094558	1043459	1145350	1088553	1164523	1111295	1209678	1154394	1262102	1199454	1307660
1.1	969567	1056672	961277	1042447	987589	1078001	1025992	1128334	1072183	1149225	1094459	1192901	1136683	1242470	1177549	1285334
1.2	947889	1033699	941876	1022661	967325	1055578	1003104	1102780	1052810	1126579	1071320	1170034	1110446	1215503	1152147	1257270
1.3	922117	1008125	920711	996940	942676	1033044	979316	1076964	1028449	1100257	1047000	1141005	1083592	1185685	1124332	1225139
1.4	895818	977369	894726	971271	916670	1001828	951687	1045490	1002771	1072440	1017526	1110075	1054357	1152550	1091185	1192063
1.5	868309	944723	868224	940870	889162	971942	923698	1011178	973400	1040108	988331	1078555	1020378	1117220	1055929	1150016
1.6	835495	912601	840382	911196	859232	939713	891220	977883	941496	1006542	955118	1044144	987610	1078868	1018604	1112262
1.7	803840	877148	810879	879176	827963	907412	858865	943525	910130	973619	922823	1006304	951308	1041365	980247	1070519
1.8	770758	842221	779562	847592	796884	872708	824516	903720	879081	939145	889991	966893	915566	1001683	942344	1028157
1.9	739161	806483	750106	811514	765187	837106	789197	868489	842989	900794	852577	931322	876725	961745	902383	986683
2	706195	773270	717597	778956	733180	802306	758376	831807	807632	865285	817815	892378	841933	920538	863971	941847
2.1	674876	736697	688540	745905	700813	768990	724189	793982	776134	828755	783966	853224	802464	881088	825846	900710
2.2	644430	703490	657891	714012	669828	732985	692033	758348	740274	793496	748819	816195	767279	839954	787269	859247
2.3	613263	669628	626564	680831	640942	700713	660032	724118	707225	758829	715802	779845	732482	800513	750931	818116
2.4	583860	636472	597643	648946	608199	669317	628595	689331	675289	724112	679426	742186	697234	763423	712753	778095
2.5	554946	605158	569645	618398	578861	636199	596661	655451	642543	689335	649296	707749	662459	725570	677560	741872
2.6	526453	575088	541086	588181	550174	602373	568026	622893	611057	656156	617369	671998	631002	690474	644053	699713
2.7	498487	545601	514113	559399	522992	574356	539377	590810	582047	623799	585184	637833	599073	654389	612052	665724
2.8	471764	515772	488282	531674	497868	544927	510628	561177	552860	591940	556590	605608	568860	620818	578131	631915
2.9	446795	488693	461945	504164	470814	514332	484101	530820	525090	561982	527184	574494	537694	587246	546690	596770
3	422666	460688	438227	476980	447393	489489	458156	501514	497303	533521	500302	545506	509204	556072	517888	563774
3.1	398167	435325	415060	451501	422501	463190	434305	474744	471838	506436	473060	514890	481609	526126	489139	532402
3.2	376456	411902	392889	426499	399296	437250	409103	447978	446127	477533	447595	488149	453446	497603	460174	501812
3.3	355967	388397	371399	403862	376645	413379	386832	424368	421926	450919	423342	460418	429588	469201	433922	474491
3.4	334663	364835	350831	380628	355901	390613	365717	398406	398811	427030	398454	435543	405382	442137	410493	447095
3.5	316546	344102	330768	359394	335608	368262	344852	375938	375976	402561	376586	410123	382105	416452	384586	419509
3.6	297342	323618	312187	340204	315967	345964	324127	354583	354717	378968	355051	386215	359511	392997	363485	395559
3.7	279076	304247	293890	319950	298913	325461	305566	333994	335051	358092	333858	365082	339718	369099	341043	373105
3.8	262306	287106	277404	301224	280598	307053	286688	312679	315389	337314	315987	342625	318604	348149	322263	349145
3.9	245771	268967	260975	282237	264238	288953	270621	296006	297675	317481	296492	323319	299654	326509	301492	329352
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